

## **Energy Harvesting Eel**

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Contract Number: N00014-98-C-0286

### **LONG-TERM GOALS**

Ocean Power Technologies' (OPT) team is developing a new power generating technology that focuses on the generation of electrical power from the flow energy of water in streams, currents, or pipes. The generating systems that are developed will be eel-like structures made from piezoelectric polymers.

The program will develop an energy harvesting unit to supply electrical power that enables small military devices to have an indefinite life when operating in a site with a flowing water energy resource.

### **OBJECTIVES**

The energy harvesting unit will resemble an eel, and will undulate like an eel in flowing water. They will be scaleable in size and have the capacity to generate from milliwatts to many watts depending on system size and the water flow velocity of the local environment. The smallest units can be deployed within a 5 cm cube and are expected to produce up to 250 milli-watts in a flow of 1 m/s.

The flow driven undulations of the eel body cause repetitive straining of the piezoelectric polymers which produces electrical voltages in the capacitor-like polymers. Each capacitor is connected to power extraction electronics that collect a pulse of electricity each time the capacitor voltages reach a positive or negative peak. These power pulses are conditioned and stored in a rechargeable battery or storage capacitor. The battery or capacitor then serves as the power source to meet the duty cycle requirements of the military device.

Program power generation goals: The theoretical mechanical power available from a cross sectional area of a water flow is given by:  $\text{Power} = 0.5 \eta A \rho V^3$  where  $\eta$  is the efficiency of the energy capture device,  $A$  is the cross sectional area in square meters,  $\rho$  is the density of water in ( $\text{kg/m}^3$ ), approx. = 1000,  $V$  is the velocity of the flow in meters per second (m/s).

As shown in the following table, a flow energy capture efficiency of 50%, a generating module efficiency of 50%, and a power electronics efficiency of 80% is used. Cross sectional areas of  $25 \text{ cm}^2$  (5x5) and  $900 \text{ cm}^2$  (30x30) are used in the table.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>1998</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1998 to 00-00-1998</b>	
4. TITLE AND SUBTITLE <b>Energy Harvesting Eel</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Ocean Power Technologies Inc,1590 Reed Road,West Trenton,NJ,08628</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002252.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

**Table 1 - Power Generation versus Water Flow**

<b>Flow Velocity (m/s)</b>	<b>Power @ 25cm<sup>2</sup> (milliwatts)</b>	<b>Power @ 900cm<sup>2</sup> (watts)</b>
1.5	844	30
1	250	9
0.5	31	1.1
0.25	4	0.14

## **APPROACH**

The challenge is to develop a small, highly reliable, family of power generators that efficiently convert environmental energy into electrical power. The ultimate size of the power generator will depend on the energy level in the environment, the generator efficiency, and the duty cycle power requirements of the remote sensor which is expected to be in the sub-watt range with peak levels up to several watts.

The flow energy capture efficiency will be dependent on the hydrodynamics design of the structure and eel, and the material parameters of the eel. Dr. Alexander Smits of Princeton University and the Autonomous Underwater Systems Institute will develop this design. Flow tests of the complete Energy Harvesting System will be performed at U.S. Navy's SPAWARSYSCEN, San Diego. This facility has extensive experience in testing subsurface systems.

The generating module efficiency is dependent on the mechanical to electrical coupling parameters of the eel piezoelectric materials, the electrode materials, and low loss lamination processes. The Materials Research Laboratory of Pennsylvania State University and Measurement Specialties, Inc. will develop the materials and processes.

The power extraction electronics efficiency is dependent on the circuit design, low losses in the electrical components, and low losses in the polymer materials. Ocean Power Technologies (OPT) has worked extensively on power extraction from piezoelectric polymers, and has developed proprietary technology to extract power pulses using resonant designs that are matched to the material properties.

OPT conceived the Energy Harvesting Eel and has developed a mathematical system model to assess the impact of material and design parameters on power generation. Using realistic parameters, the power goals shown in the above Power Generation versus Water Flow Velocity table can be achieved during the program.

## **WORK COMPLETED**

Production of various mechanical eel bodies has been completed. They utilize different material thicknesses of polyurethane and PVDF and employ different adhesives and waterproofing techniques. From these we have a better understanding of the optimal waterproofing and bonding materials. Dr. Smits of Princeton University is currently compiling data pertaining to the deflections of these various mechanical eel bodies in a flow tank, and the most promising initial combinations have been identified.

The original concept of the eel body incorporates multiple electrodes that span the length of the eel body; this design anticipates high frequency shedding, which aids in power generation. During initial flow tank analysis it was noted for both the Polyurethane and PVDF eels that high frequency vortices lose much of their small amplitude due to damping by the body. The best action was obtained from larger radii vortices that bent the eel in a single mode. OPT has therefore modified the design for this phase to include a simpler and larger single capacitor (single electrode pair) which will see a deflection of approximately 5 in. MSI has completed the artwork for the electrodes and wiring of the first electrically active eels and they are being fabricated. Different parameters are being reviewed in vortex creation that include the shape of the bluff body and the distance between the bluff body and the eel.

OPT has completed the assembly of a new small laboratory material test generator. The generator can be modified to also operate in a bending mode for strain testing in the eel application.

Work is continuing on the tuned circuit method of energy extraction and has begun for investigating the computer and I/O requirements instrumented testing of coordination control software. The design of a DC-DC of voltage converter has begun that will produce 2 KV from 3 V for the bias power.

Some PVDF:TrFE material has been obtained from MSI. It will be irradiated by MRL to convert it to an electrostrictor. OPT will evaluate its performance as was done with polyurethane.

## **RESULTS**

The summary conclusions of work performed to date are:

- The behavior of the voltage vs. strain obtained by OPT was as expected
- The biggest problem encountered was current leakage through the Polyurethane due to the Bias Voltage
- The MRL will evaluate other soft polymers that have similar Young's Modulus and d31, but less leakage through the material
- Mechanical eel bodies have been produced from both PVDF and polyurethane and successfully flow tank tested
- Natural latex rubber and densil adhesive have been found to be the optimal waterproofing and bonding materials

## **IMPACT/APPLICATIONS**

A successful program will result in new, small, light weight, quiet power generating units that can recharge the batteries or capacitors of a distributed robotic group, or remote sensor array, to extend their mission life indefinitely in regions containing flowing water. Most importantly, availability of this technology will make possible new mission scenarios never previously considered by the DoD because of the problems inherent in remote power supply.

## **TRANSITIONS**

The development work being performed on the electrostrictive materials is synergistic with other programs at the Pennsylvania State University's Materials Research Laboratory.

## **RELATED PROJECTS**

Under its current development program, OPT is working on the construction of prototype power generating systems based on both electromagnetic technology and the piezoelectric polymer PVDF. OPT has also had (i) a Phase I SBIR Contract from Office of Naval Research to investigate the feasibility of an OPT Generator located either at or below the surface to provide up to 1 kW of power to recharge the batteries of Autonomous Underwater Vehicles; (ii) OPT has received the Phase II contract for the AUV program to deploy and test a 1 kW surface system in the ocean; (iii) OPT, with Pennsylvania State University, has received Phase I and II STTR contracts to explore the use of electrostrictive polymers as “electric field induced” piezoelectric generators. These materials have the potential of providing significantly improved performance, over the presently used PVDF, in OPT’s generators.